Superheterodyne Oscillator Tracking and Super Control Tubes

LESSON ND-23

SPRAYBERRY ACADEMY of RADIO

ESTABLISHED 1932

PUEBLO, COLORADO

The above view shows a modern superheterodyne type receiver with automatic push-button tuning and phonograph record reproduction. The tuned circuits of this radio receiver operate on the principles described in this lesson. Courtesy of Crosley.

SUPERHETERODYNE OSCILLATOR TRACKING AND SUPER CONTROL TUBES

LESSON ND-23

This lesson is the second in a series on the superheterodyne type receiver. As you have already learned, this type of receiver must be precisely engineered else it will not work. For the same reason, it is essential that you understand it thoroughly else you will not be an expert on how to repair and keep it in operation. So as you study this and other lessons of a similar nature, do not infer from the nature of the studies that we are teaching you to become a design engineer. There are many men today working with superheterodyne

circuits who attempt to repair them but do not know *why* they do certain things. Consequently they do much unnecessary work and fail completely on many repair problems. It is our desire to so train you that you make no haphazard tests and adjustments. The qualified radio man makes certain tests and adjustments because his training tells him that it is exactly the thing to do. Hence, there is no guess work but a definite reason for every procedure. So be sure and keep this qualifying factor in mind as you study the lesson.

You are going to learn about oscillator tracking (a tuning problem), certain requirements of tuned RF or preselector stages, using a type of tube you have not heretofore studied in your SAR Course (Super Control Tubes), interference problems, and, finally, you will study the elements of a complete superheterodyne receiver in this lesson. Because of the fact that the oscillator in a super *must be tuned to a different frequency* than the RF or preselector stages and because one tuning control is required to operate both the RF and Oscillator stages, this introduces some complex problems, and you should know how they are solved. You need to know this in order to know how to adjust the tuned circuits when they get out of adjustment. With this properly explained you take up the study of the Super Control tube and will understand why these must be used in the preselector stages in order to avoid a certain type of interference. Other types of interference peculiar to the super circuit are discussed next in this lesson. Finally, you study a complete super receiver. When you come to it do not be disappointed if every part of its circuit is not entirely explained. Lessons following this one will take up those things not explained in this lesson. The purpose of using the complete super at this point in your studies is to show you how the main points in this lesson are applied. For more information on AVC, switching systems, etc., see other lessons following this one.

OSCILLATOR TRACKING

Early super receivers were large and cumbersome affairs. In many of the early designs, the oscillator was a separate unit completely and in a cabinet by itself. This would be placed several feet away from the receiver, the distance depending upon the *amount of coupling* desired. The difficulty of tuning the oscillator circuit while tuning the RF circuit led to incorporating the oscillator in the same cabinet as the receiver but with separate tuning controls. As the tuning dial division numbers of the oscillator did not agree with the dial numgers of the RF tuning control, this system presented many more difficulties. Not being interested in the technical operation of the receiver, the average owner of these early type receivers did not take the trouble and time to learn how to adjust both circuits for proper reception. Later developments arranged the variable condensers so that two or more rotors were on the same shaft; thus, the tuning was simplified. This arrangement of a single rotor shaft for two or more variable condensers is called a *gang condenser*. The use of a

This photograph shows the control desk and control panels of a modern broadcast transmitter. High power must be handled here but the tuning principles are the same regardless of whether a receiver or transmitter is involved. Courtesy of Westinghouse.

gang condenser, however, presents other problems, as you will see in your study of this lesson.

The evolution of the modern *single* tuning control for the super is the result of good mathematical engineering. As you will recall, the oscillator frequency *differs* from the signal received by an amount equal to the chosen IF. *This difference must be exactly maintained over the tuning range of the receiver.* Thus, the major serious problem is to design two tuned circuits, each of which must cover a *different* range of frequencies, both operated by the same control shaft and so proportioned that the difference frequency will remain the same regardless of the position of the single tuning control. If the two identical condensers were tuned to two identical coils, the problem would be quite simple. Since this is *not* the case, because of the difference in frequency, further adaptation is necessary to fit the requirements.

The relation of capacity to frequency is a most interesting study and exceedingly useful in all phases of electronics. An understanding of this relationship will show you why the tracking of tuned circuits is such a problem. An oscillator tuning system is said to *track* correctly when its tuning condenser, on the same shaft as the RF and detector tuning condensers, maintains the necessary frequency difference over the total tuning range. The only practical way in which a thorough understanding of this probelm and its solution may be ob-

tained is through the use of simple mathematics. By use of computations involving no more than ordinary multiplication, division and square root, answers to the various problems involved may be found. As you will remember from a former lesson, the resonant frequency of an LC circuit equals—

$$(1) \qquad f = \frac{1}{2\pi\sqrt{LC}}$$

This formula expresses the basic *relationship* of capacity, inductance and frequency in fundamental units.

In the usual receiver, the inductance is fixed and the capacity varies. This limits the study to the effect on frequency when the capacity is changed or varied. To get a clear idea of the difficulty, the ratio of the condenser capacity when tuned to the highest frequency of the band must be determined.

As it is not feasible to deal with quantities in the form of a square root, the first thing to do is to eliminate this sign from formula (1). Since both sides of the formula are equal, their squares must also be equal so the formula remains true if both sides are squared as fol lows:

$$(2) \qquad f^2 = \frac{1}{4\pi^2 LC}$$

This form permits the removal of the square root sign from the quantities LC.

As this is just a formula, two equations must be developed from it for comparison. The first equation will be for the first frequency and the other for the second frequency. These two frequencies could be the extreme limits of a band of frequencies—for example, the limits of the broadcast band from 540 to 1600 KC. For simplicity, it will be assumed that the lowest frequency will be identified as f1 and the highest frequency as f2. Because the formula is true for *any* frequency, it is not necessary to state the number of cycles per second. *The ratio of f1 to f2 is the important information required.* In other words, how many times greater or less is f1 than f2. To find the ratio of 5 to 10 it is merely necessary to divide 10 by 5. Similarly, to find the ratio of the two frequencies involved here, it is simply stated as $\frac{f2}{f1}$.

It makes no difference what numbers are involved as it is simply necessary to know how this value $\frac{f2}{f1}$ compares with the actual circuit capacity ratio for the two frequencies. Obviously, the capacity will be different for each of the two values f1 and f2. Assume, then, that the circuit capacity will be C1 when the frequency is f1, and, when changed to another value, C2, the frequency will also change to f2. This ratio $\frac{f2}{f1}$ becomes something that can be evaluated as—

$f1^2 = \frac{1}{4\pi^2 LC_1}$ from formula (2)

also:

$f2^2 = \frac{1}{4\pi^2 LC_2}$

The ratio between these two equations is equal to:

$$(3) \qquad \frac{f2^2}{f1^2} = \frac{\frac{1}{4\pi^2 LC_2}}{\frac{1}{4\pi^2 LC_1}}$$

Note that here the equations have been expressed as one being divided by the other. Carrying out the division—

$$\frac{f2^2}{f1^2} = \frac{1}{4\pi^2 LC_2} \times \frac{4\pi^2 LC_1}{1}$$

(This is a mathematical principle you have probably already learned from your SAR Math Book). It is now possible to cancel all numerator terms with all similar denominator terms, obtaining—

(4) $\frac{f2^2}{f1^2} = \frac{C1}{C2}$ which is the *valuable relationship* which was sought at the start. The basic formula sought is now obtained because nothing remains except the two frequencies and the two capacities.

For further study, suppose there is a capacity of 500 mfd. maximum in a circuit tuned to 500 KC and it is desired to change the capacity so that the circuit will tune to 1000 KC. The first frequency is 500 KC (f1) and the second 1000 KC (f2). Their ratio is $\frac{1000}{500}$ or 2, and their square is $\frac{1,000,000}{250,000}$ or 4 (as $1000^2 = 1,000,000$ and $500^2 = 250,000$). Therefore $\frac{f2^2}{f1^2} = 4 = \frac{C1}{C2}$. The capacity C1 tuned to 500 KC has a value of 500 mmfd.; therefore, $4 = \frac{500}{C2}$ or $C2 = \frac{500}{4} = 125$ mmfd. which is ¼ of 500. In doubling the frequency of the circuit, *note the capacity has been divided by 4.*

Taking a practical problem of a tuned circuit for the broadcast band, using a 365 mmfd. tuning condenser for 540 KC, what will be the capacity at 1600 KC? For convenience, invert the formula as at (4) to read directly in terms of the new capacity which is sought; thus—

$$\frac{f2^2}{f1^2} = \frac{C1}{C2}; \quad C2f2^2 = C1f1^2$$

$$\text{and} \qquad C2 = \frac{C1f1^2}{f2^2}$$

Having values as follows:

C1 = 365 mmfd.
f1 = 540 KC
f2 = 1600 KC

And, by substitution—

$$C2 = \frac{365 \times 540^2}{1600^2} = \frac{106,434,000}{2,560,000}$$

= 41.5 mmfd. which is the new capacity value. It may be further shown that the larger capacity when at maximum is $\frac{365}{41.5}$ or 8.79 times larger than the new or lower capacity.

In this way, it is known that to tune over the broadcast band from 540 to 1600 KC a variable condenser must be chosen having a maximum to minimum ratio of at least 8.79 to 1.

It is necessary to determine how the oscillator frequency can be made to *always* be *different* than the signal to an amount equal to the IF. For example, if the IF is to be 456 KC and the RF circuits are to cover the bands from 540 to 1600 KC, then the oscillator range must include 540+456 KC or 996 KC at one extreme position and 1600+456 KC or 2056 KC at the other extreme position. A 456 KC difference *must always be maintained* at any position within the broadcast band in this example—the same principle applies, of

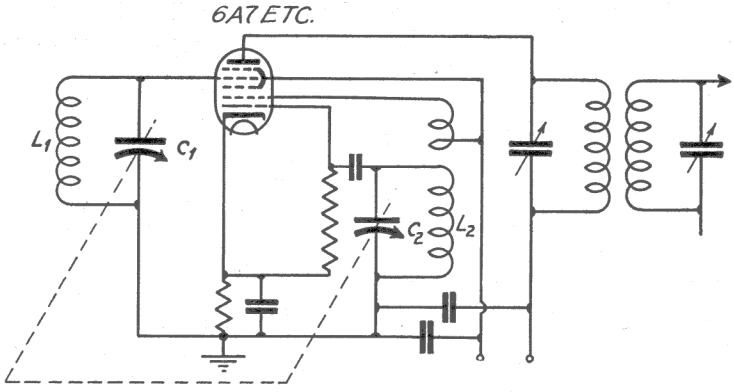


FIG. 1

course, to super receivers which use other IF values.

At first thought, this might seem to be an easy task. It would seem that the oscillator tuning condenser could simply be made smaller for this purpose. A close examination, however, will disclose that the problem involved is more complicated than it first appears. In Fig. 1, a typical basic first detector-oscillator circuit is illustrated using the 2A7, 6A7, or other similar type tube. Circuit L1-C1 is the pretuner and L2-C2 is the oscillator tuned circuit. The resonant frequency to which L1-C1 will respond may be found from the usual resonant formula as follows:

$$f = \frac{1}{6.28\sqrt{L1C1}}$$

Where: f = cycles
C1 = farads
L1 = henries

Both sides of the equation should now be squared to give:

$$f^2 = \frac{1}{39.5\ L1C1}$$

If the units are changed to Kilocycles, microhenries and microfarads, the form of the formula may be changed to read as follows:

$$f^2 = \frac{1{,}000{,}000}{39.5\ L1C1} = \frac{25{,}330}{L1C1}$$

The term f in the foregoing is still squared. If only f is wanted, the form of the formula must be changed to:

$$f = \sqrt{\frac{25{,}330}{L1C1}}$$

If C1 is moved to the left side of the equation, the formula must be changed to read as follows:

$$(5) \qquad C1 = \frac{25{,}330}{L1f^2}$$

(Notice, in this case, the term f has been squared again. All of the foregoing math principles are explained in your SAR Math Book).

Since the *change in frequency* which will result in a given change in capacity is the important detail, it is necessary to transpose formula (2) to read—

$$(6) \qquad f^2 = \frac{25{,}330}{C1\ L1}$$

The difference in formula (6) with respect to (2) is that in (6) the units are Kilocycles, microfarads and microhenries.

Obviously, since C1 is a part of the denominator here, its value will

affect the frequency *inversely*—that is, as the capacity increases, *the frequency will decrease* because the fraction will reduce in value as C is increased. Therefore, to raise the frequency over and above the RF which will be at 540 KC as a minimum, a corresponding minimum for the oscillator will have to be 540+456 or 996 KC. This means that capacity C2, which tunes the oscillator circuit, must be reduced in value with respect to that required for C1 which tunes the RF or preselector.

To illustrate, start with C2 equal to C1 and L2 equal to L1 as has been assumed. Notice that no capacity or inductance values have been mentioned as it is merely desired to find the *ratio* of one capacity to another. To find the ratio of two values, simply divide the one by the other. One is equal to $\frac{25{,}330}{L1\ f1^2}$ as in formula (5), and the other is equal to $\frac{25{,}330}{L2\ f2^2}$ Therefore, their ratio $\frac{C2}{C1}$ is equal to:

$$\frac{\frac{25{,}330}{L2\ f2^2}}{\frac{25{,}330}{L1\ f1^2}} \quad \text{or} \quad \frac{f1^2}{f2^2}$$

In this case f1 = 540 and $f1^2 = 540^2 = 291{,}600$ and f2 = 996 whose square is 992,016—and since L1 is equal to L2, they cancel, resulting in $\frac{C2}{C1} = \frac{291{,}600}{992{,}016} = .293.$

This means that if C1 has a maximum value of .000365 mfd., C2 must have a value of .000365×.293 or .000106945 mfd. To six decimal places this will be .000106 mfd.

Bearing this reduction in mind, you can easily see that the oscillator tuning condenser *must have a lower maximum value* (because for the oscillator, f equals 996 KC) than the RF tuning condenser (for the RF, f equals 540 KC) to permit the oscillator to tune 456 KC above the signal frequency at all times.

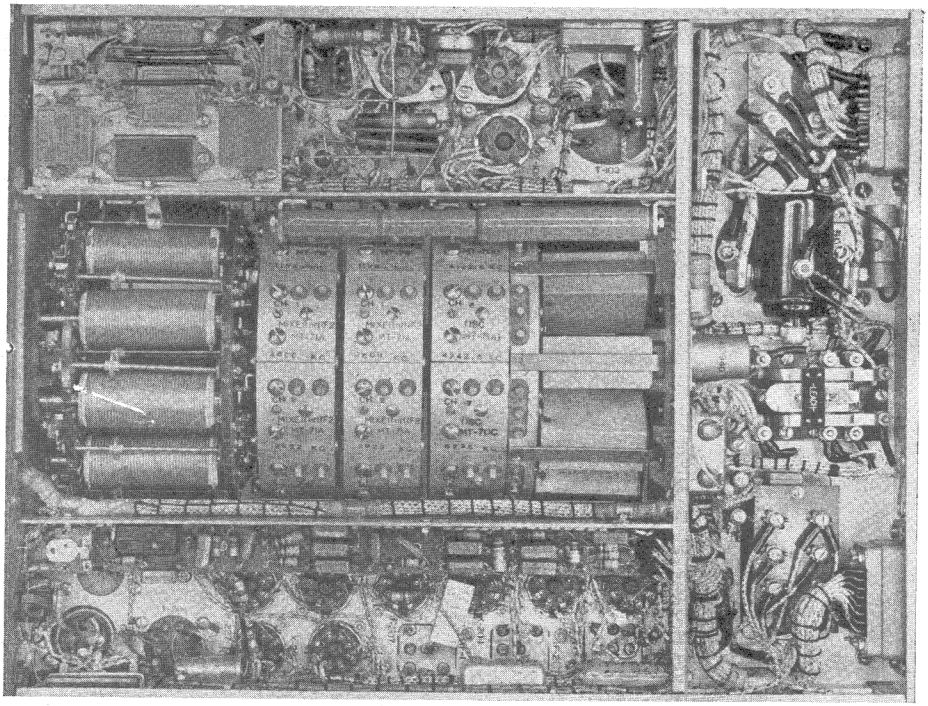
Now, advancing towards the higher frequencies with the tuning mechanism tuning in various stations, the oscillator frequency must change the same number of KC as the pretuner or preselector. At first this might seem quite regular and requiring not further study. However, as some higher frequency is selected, the highest in the broadcast band being 1600 KC, it may easily be seen that another problem arises. The oscillator must now be tuned to 1600+456 or 2056 KC. It is necessary to know what *ratio* each capacity must be reduced to be in tune with the signal from the maximum to the minimum frequency. The pretuner tunes from 540 to 1600, a ratio of $\frac{1600}{540}$ or 2.9, and since $f1^2 = \frac{25{,}330}{L1\ C1}$ and $f2^2 = \frac{25{,}330}{L2\ C2}$, the ratio of the two frequencies in terms of L and C is equal to:

$$\frac{f2^2}{f1^2} = \frac{\frac{25{,}330}{L2\ C2}}{\frac{25{,}330}{L1\ C1}}$$

and

$$\frac{f2}{f1} = \frac{\sqrt{\frac{25{,}330}{L2\ C2}}}{\sqrt{\frac{25{,}330}{L1\ C1}}} = 2.9$$

Still considering that L1=L2, the equation is squared to give:



Here is shown the underside view of a Bendix combination transmitter receiver. It is for two-way telephone conversation between ground and planes in flight. It operates between 2500 and 13,000 kilocycles and has ten crystal controlled channels. Note the neat arrangements of parts. This is an example of tuning for both transmitter and receiver in one unit.

$$\frac{\frac{25{,}330}{L2\ C2}}{\frac{25{,}330}{L1\ C1}} = (2.9)^2 = 8.41, \text{ and}$$

hence $\frac{C1}{C2} = 8.41.$

This means that the minimum value of the RF signal tuning condenser is equal to $\frac{1}{8.41}$ of its maximum value or $\frac{.000365}{8.41} = .0000434$ mfd.

The same treatment applied to the oscillator tuning condenser equals $\frac{2056}{996} = 2.06$ which squared equals 4.24 as the *maximum to minimum ratio* for the oscillator condenser covering its range. Because its maximum value is .000106 mfd., then $\frac{.000106}{4.24}$ equals .000025 mfd.—or its minimum value.

Finally it is necessary to compare the two maximum capacity values with the two minimum values; thus—

$$\frac{\text{(RF) C1 max.}}{\text{(Osc) C2 max.}} = \frac{.000365}{.000106} = 3.4$$

$$\frac{\text{(RF) C1 min.}}{\text{(Osc) C2 min.}} = \frac{.0000434}{.000025} = 1.7$$

As the RF tuning condensers and the oscillator tuning condenser are tuned to increasingly higher frequencies, *their capacities become more and more alike.* That is, *the difference between one and the other becomes less and less, or the ratio of the larger to the smaller*

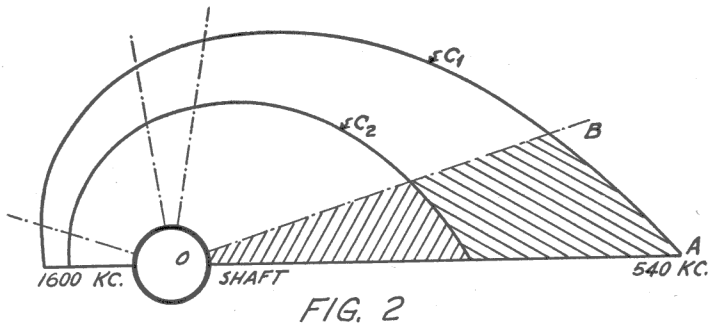


FIG. 2

one approaches a ratio of 1. When both are maximum, the larger is 3.4 times greater than the smaller one, but when both are minimum, C1 is only 1.7 times as great as C2.

Obviously, if the oscillator and RF coils are alike, *the condensers cannot be alike* as the capacity of C1 (for the RF stages) must change more rapidly than C2 (for the oscillator stage) when tuning. One convenient and popular method of accomplishing this correction of the problem is to shape the plates of the oscillator tuning condenser so that its *capacity* changes *more slowly* than that of the RF tuners. For a view of the oscillator and RF tuning condenser shapes, refer to Fig. 2 which shows a side view of the rotor plates of C1 and C2. Note that at the 540 KC end of the plates, C1 is somewhat larger than C2. In any small angle such as AOB in Fig. 2, the area of C1 at this setting is 3.4 times larger than C2. As the condenser is tuned, the area of C1 diminishes more rapidly than that of C2 until at 1600 KC the area of C1 is only 1.7 times as large as that of C2. You will recall that these are values obtained from the previous calculations.

In a great many super receivers, the method of reduced plate area for the oscillator tuning condenser is employed to make the oscillator tuning system *track* with the RF tuned stages even when the oscillator coil has a different inductance than the RF coil. Upon examination of a receiver using this system, you will immediately notice that the plates of the oscillator tuning condenser are smaller than the others. This will identify the receiver as a super and will also identify the oscillator tuning condenser.

In many cases, it is highly desirable to use the same size tuning condensers for all stages in super receivers and accomplish the correct tracking in some other way than using special size plates for the oscillator.

As you already know, a condenser connected *in series* with one of the main tuning condensers will *decrease* the *total circuit capacity* thus *raising the frequency* of the oscillator. You also know the relations or ratios necessary for these capacities from your study of this lesson. The use of a series condenser to provide proper tracking and to avoid special size plates for the oscillator will now be explained. The series connection for the two con-

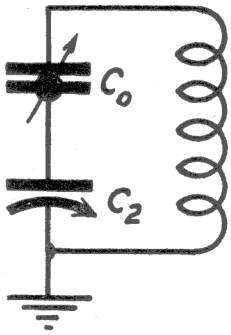


FIG. 3

densers is shown in Fig. 3. The second condenser is labeled Co and C2 is the main tuning condenser for the oscillator stage. C1 will serve to identify the main tuning condenser for the RF or preselector stage. (Not shown in Fig. 3). C1 and C2 are, of course, identical in capacity. It is evident that the total circuit capacity for the RF circuit at 540 KC should be .000365 mfd. and for the oscillator at 996 KC it should be .000106 mfd. The needed series capacity value to make this total from the .000365 mfd. value is found as follows:

$$Co = \frac{C2\ Ct}{C2 - Ct}$$

where Ct is the total capacity desired. Thus, to find the value of Co, the problem is set up as follows:

$$Co = \frac{.000365 \times .000106}{.000365 - .000106}$$

$$= \frac{.00000003869}{.000259}$$

$$= \frac{.03869}{259}$$

$$= .00014 \text{ mfd.}$$

Thus, at 540 KC each capacity is correct in value, one (RF) being .000365 mfd. and the other being .000106 mfd., formed by a .000365 mfd. condenser in series with a variable *padder* condenser Co, adjusted to .00014 mfd. Condensers *C1 and C2 alone* will both have *minimum capacity values* of .0000434, but this value in series with Co, whose value is .00014 mfd. will give a total oscillator capacity Ct, at minimum of—

$$Ct = \frac{.0000434 \times .00014}{.0000434 + .00014}$$

$$= \frac{.000000006076}{.0001834}$$

$$= \frac{.06076}{1834}$$

$$= .0000331 \text{ mfd.}$$

Note that former calculations for special size plates for the oscillator tuning condenser at 2056 KC calls for a minimum value of .000025 mfd. With the padding condenser Co, however, a value of .00014 mfd. is needed which will make the circuit tune to a lower frequency than 2056 KC. It is impractical to *reset* Co for the proper value so that the total of the two (C2 and Co) will be .000025 mfd. This was set for 996 KC as a minimum and thus would be off at this frequency if Co was reset for 2056 KC. It is evident that the max-

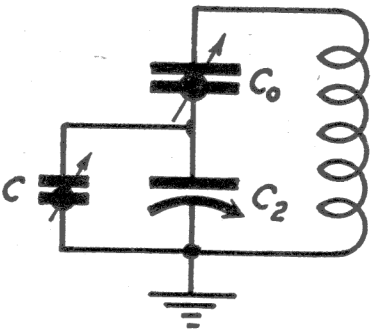


FIG. 4

imum to minimum capacity ratio of the series combination (C2+Co) has been reduced below 4.24. This is the squared ratio value, you will remember which was found to be correct for the tuning range of the oscillator.

Now, in preserving the original requirements of maximum to minimum ratio of 3.4 at maximum and 1.7 at minimum you may solve the values of all the capacities involved. In this way you can determine what *additional condensers* are necessary *for a complete solution of the oscillator tuning problem* when the tuning condenser is the same size as that of the RF.

Each main tuning condenser is provided with an extra *trimmer* condenser which is connected in parallel with it and included in its capacity of .000365 mfd. This small trimmer condenser is mounted on the frame of the tuning condenser and is adjustable by means of a tuning alignment tool. Therefore, to reduce the oscillator capacity from .0000434 mfd. to .000025 mfd., which is the correct value in this case, it is only necessary to adjust the oscillator trimmer C as in Fig. 4 and thereby automatically subtract .0000184 mfd. from .0000434 mfd. leaving the desired .000025 mfd. Of course, this capacity value will also be subtracted from the condenser at maximum capacity, but it will be very little more than 1% and hence will affect the lower RF frequencies very little. The trimmers on the RF tuning condensers may also be adjusted in the same way, and thus the two sections of the gang condenser will track correctly. Your SAR Service Course lessons will give complete details on how to adjust the tuned circuits of all types of radio circuits.

A graphical representation of the range of the oscillator tuning adjustment is shown in Fig. 5. The series padding condenser Co and the high frequency trimmer C of Fig. 4 controls the position of the line in the graph labeled Osc-C2. The adjustments are graphically equivalent to a tailor's technique of padding clothing, hence the term *padding condenser* for Co. More broadly speaking, the process of *padding* a super includes adjustments for both Co and C in Fig. 4. The padding condenser, as Co is called, has a maximum effect on the frequency of the circuit at 540 KC because it forms a *major part of the total circuit capacity* while *at 1600 KC it is quite a minor part of the total capacity of the circuit.* At 1600 KC, Co is extremely large as compared to C2 and thus, following the law for series capacities, becomes a minor part of the total circuit capacity.

Because of these facts you can see that the change in oscillator frequency brought about by the series padder for increasing frequencies becomes less as tuning continues towards the higher frequencies. As you see, the dotted lines for trimmer C in Fig. 5 converge as the frequency decreases. The dotted and dashed lines in Fig. 5 represent the limits of frequency change which can be brought about by adjusting the padding and trimming condensers. *Note how the series condenser Co affects the lower frequencies and the shunt condenser C of Fig. 4 affects the higher frequencies* in the graph of Fig.

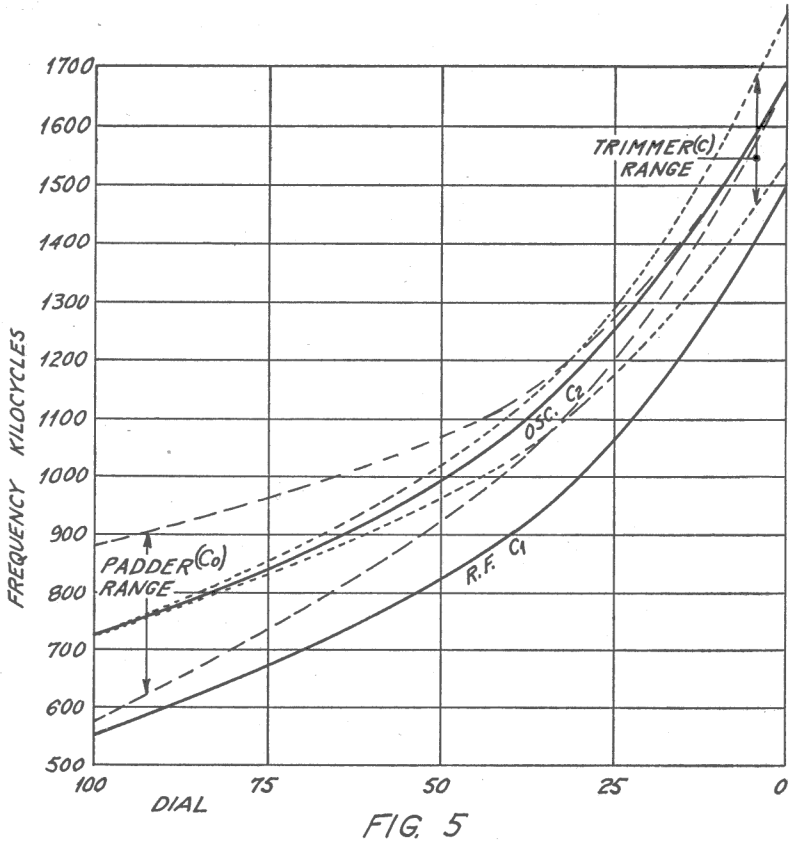


FIG. 5

5—hence, the names low frequency padder and high frequency trimmer.

As stated, the oscillator trimmer C in Fig. 4 has the greatest effect on the oscillator frequency at the highest frequency as it, being in parallel with the tuning condenser C2, forms a major part of the circuit capacity when the complete tuner is adjusted to a high frequency, around 1600 KC. Thus, for complete *tracking* of the oscillator with the RF circuits, the padding condenser must be adjusted at some frequency between 540 and 600 KC. The trimmer C should be adjusted to some frequency between 1400 and 1600 KC. The inductance for the oscillator coil may be the same as that of the RF stages or as is more often the case the inductance of the oscillator may be different from that of the RF coils. In either case the same principle of padder and trimmer condensers is employed for the oscillator circuit.

There are several ways of wiring the component parts of an oscillator tuned circuit. The rotor shaft of the oscillator tuning condenser is usually integral with the other condenser shafts, and this common shaft is grounded. For this reason, besides the arrangement shown in Fig. 4, there is also the arrangement shown in Fig. 6. In some oscillator circuits the major part of the total padding

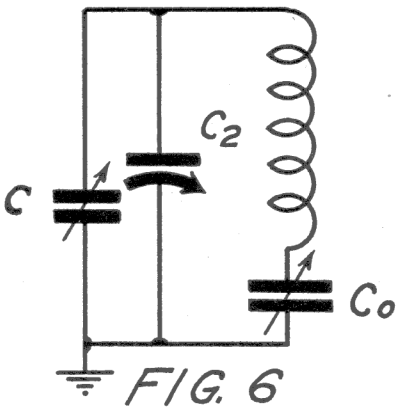


FIG. 6

condenser Co value is in the form of a fixed mica condenser, and a small value trimmer, Cx, is placed across it as in Fig. 7. Both the arrangements of Figs. 6 and 7 are used extensively, and some companies engineer their part values so closely that the series condenser Co is in the form of a fixed mica condenser requiring no adjustment at all at the lower frequencies.

You will see one of the foregoing described oscillator tuned circuit arrangements in every super receiver. In some cases, the high frequency trimmer C will be placed across the entire circuit, but this can only be possible when the balance of the circuit is like Figs. 3 and 4.

To complete the story of tuning of super circuits, refer to the complete system shown in Fig. 8. The three main tuning condensers are

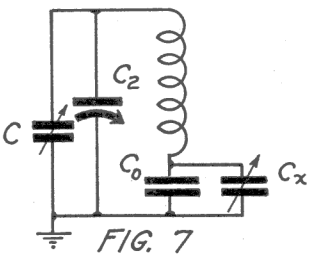


FIG. 7

C1, C2 and C3, all alike, with a common shaft grounded and tuned by a single knob as indicated by the dotted lines. Condensers Ca and Cb are high frequency trimmers for fine adjustment of C1 and C2 which tune the RF stages. Not being adequate for alignment compensation at all frequencies, these condensers Ca and Cb, are only part of the complete scheme of tuning in many receivers. At one or both ends of the rotor sections of each of the main tuning condensers, as well as for the oscillator tuning condenser, the end rotor plates are split *radially* making a number of individual *fan-shaped* sections. Usually there are ten such sections for each, covering a 100 KC space in the tuning range.

The capacity of any of the main tuners may be slightly increased or decreased at any dial setting by this method by bending in or out each split section of the individual rotor plates. In this way variation in each tuned circuit may be controlled. In other receivers, split sections of the rotor plates are not used. In this case the various parts which make up the tuned circuit must be held to very close tolerance values in order that there will be a minimum of variation of part values in each tuned circuit. If too much variation in part values is permitted, the tuned circuits will not track together and thus cannot be operated from one control shaft.

You should observe that the trimmer adjustments influence the total circuit capacity and not the relative capacities for various dial settings. If the capacity of one of the main tuning condensers in-

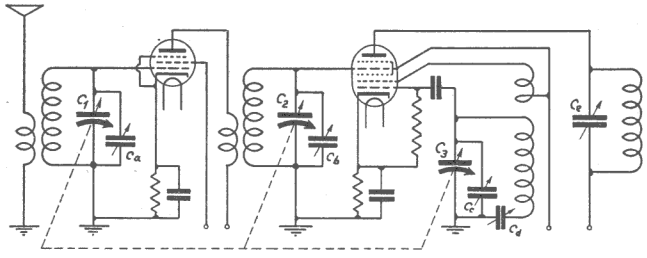


FIG. 8.

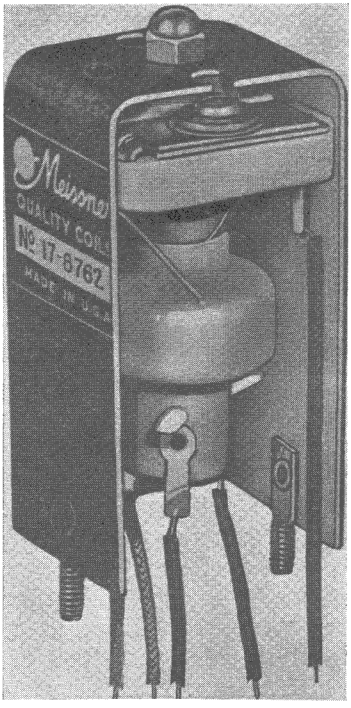
creases slightly more than the others at, say, 1200 KC, after the trimmers have been accurately set at 1400 KC, the split section of the rotor of that condenser in imediate mesh with the other plates should be bent out to slightly *decrease the capacity* of that condenser to bring it into proper alignment with the others. Now, if one of the condensers has a different tuning characteristic than the others, two of them can be adjusted to this one. For this reason, in many cases, one condenser does not have its rotor plates split, and it may not have a trimmer. In this case, the rate of capacity change per degree of dial movement of the other condensers is adjusted to this one.

From this arrangement you can see that complete and perfect alignment of the RF and oscillator sections of any super can be obtained through the use of the split rotor adjustments, the trimmer and the oscillator padding condensers.

Infrequently, the split sections or segments of the rotor are provided with a brace mechanism and a set screw for the *fine* adjustments of each leaf with a wrench rather than the inaccurate method of bending plates by hand as will be pointed out in your Service Course lessons. Referring to Fig. 8 again, the RF stages are brought into tuning alignment by adjustment of the high frequency trimmers Ca and Cb. The oscillator stage is brought into alignment at 1400 KC by adjustment of the high frequency trimmer Cc. At the lower frequencies, the oscillator tuned circuit is brought into alignment at around 600 KC by adjustment of Cd. The IF trimmer Ce provides adjustment for the input of the IF amplifier.

Methods of connecting signal generators, the method and order of making tuning adjustments, etc., will be discussed in full in your SAR Service Course lessons to come to you later.

Other systems of super tuning have been developed in which the resonance of a tuned circuit is adjusted by other means than varying a capacity. Among these is the *permeability tuning* method. This system depends on changing the inductance of a coil by means of a *movable iron dust or powder core*. These coils are generally wound on a form about the size of an ordinary pencil. The winding for broadcast reception is usually about 2 inches long. A metal core in the form of a rod is arranged to move into and out of the coil. The core is made of very fine iron powder mixed with a plastic binder. The coil is connected to a trimmer condenser of the correct



This is an example of a typical IF transformer. A cutaway view is shown to reveal the impregnated coils and trimmer condensers. Courtesy of Meissner.

capacity to *tune* the combination to the *highest frequency* of the range to be covered with the core *out*. As the core is inserted the inductance will increase thus lowering the resonance of the circuit. The same circuits for oscillator, RF stages and detectors are used as are employed with variable condenser LC circuits. The problems remain the same and are solved in the same manner. Tracking is accomplished in some other cases by graduating or tapering the core. In other receivers a system of cams and levers move the oscillator core to the correct position as the RF and detector circuits are tuned. More often, however, the tracking problem is solved by means of padder and trimmer condensers exactly as explained in the previous condenser tuned cases.

THE DESIGN OF SUPER RF STAGES

The principles of the applications which have already been discussed are not sufficiently adequate for an understanding of modern circuit design. For this reason it is necessary for you to study the details of radio frequency (RF) amplifiers in this and the following lesson. The facts to be presented will form a basis to enable you to know why, for example, a wave trap is used and why a *super-control tube* is used in one circuit and not in another. The reasons for using double tuning (preselection) before the first detector and other similar design elements will be shown. You have learned in previous lessons of your SAR course that the *proportionality* between the grid and plate *voltages* determines the distortion of a signal. This has been discussed as to its effect on detectors and audio frequency amplifiers. In an audio amplifier this distortion must be avoided or held to a *minimum*. In detector circuits distortion is often deliberately introduced to provide *proper* detection. The next consideration is to determine the effects of this type of distortion in a radio frequency amplifier.

If a type 24, 24A, 57, 77 etc., (known as sharp *cut-off* tubes) tube is used as a first RF amplifier immediately following the first tuned circuit, a large signal will cause the control grid to swing along the curved region of the Eg-Ip characteristic of the tube. Under these conditions, as you have

studied, the tube will act as a detector. At this point in the RF circuit, detection has no value *and must be minimized or prevented.* The degree of distortion of the incoming signal wave—that is, the degree to which the plate current changes becomes *disproportional* to the grid voltage changes—depends on how much of the Eg-Ip curve is covered by the grid voltage and plate current or depends on the amount of grid swing. The smaller the segment of a circle or curve of uniform curvature, the more nearly straight it is. Just a small pond or lake will appear to have a perfectly flat surface whereas, if you think in terms of a large ocean, you know that it has considerable curvature. Thus, a 1 microvolt (.000001 volt) signal will produce much less detection effect than a 1 millivolt (.001 volt) signal. For the sharp cut-off type tube, as the grid becomes more negative, the curvature is greater and a 1 millivolt signal will allow for more detection than at a lower bias.

Moreover, it is apparent that the *steepness* or, as it is called, the *slope* of the Eg-Ip curve determines the amount of amplification. The plate current will change greatest for a given signal where the slope of the curve is the steepest. See your lesson on high frequency amplification and detection for more details of this characteristic.

You will remember from previous studies that as the bias is increased, the slope of the curve of the tubes gradually decreases at first, but, as the bias is further increased (due to the signal activity on the grid), the slope of the curve becomes increasingly smaller as the *curvature* is greater.

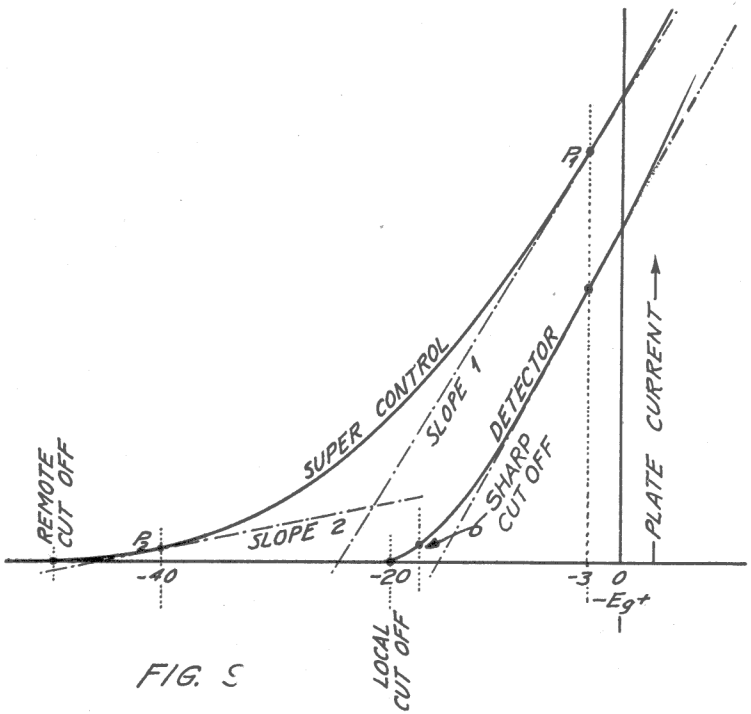


FIG. 5

A more comprehensive picture of this situation is given in Fig. 9. The curve marked detector represents the character of the plate current-grid votage relations for a tube such as the 22, 24, 24A, 32, 36, 57 or 77. Within a few volts of the cut-off point (bias sufficient to stop plate current) the curvature of the characteristic curve is greatest. Here the detector action is maximum and the change in amplification, as the bias is increased, is most rapid. That is, the amount of amplification obtained reduces most rapidly as the bias is increased through this region. Obviously, the slope changes are also most rapidly made here.

The fact that the grid bias (remember that the net bias is the normal bias plus the signal) may be used as a means of controlling the gain of a stage of amplification due to this change in slope of the characteristic curve would seem to provide a valuable means of controlling volume. The introduction of detector action, however, does not permit the use of this type of tube for this purpose.

With each variation in average carrier power due to modulation, the amplifying ability of the tube is changed. If the net grid bias is anywhere in the negative region, the tube will amplify slightly more for increased carrier energy than for low carrier energy. The effect is, of course, accentuated when the tube is operated on the maximum curvature section of the Eg-Ip characteristic.

Now if the received signal happens to be an unwanted signal somewhat off resonance, these variations of amplification will modulate any carrier which is intended to be received. In other words, where such a tube performs the function of detection, the detected signal will modulate any carrier being received. If the desired carrier signal is strong, it will force the control grid of the RF tube a good distance along the curvature of the Eg-Ip curve and *this causes an unwanted station signal to be brought in simultaneously with the desired signal.* Although the two signals may have widely different frequencies, each will modulate the other and any RF carrier to which the RF stage is reasonably closely tuned will carry both modulations to the detector circuit. Because the signals of the two or more carriers *cross* in this fashion in the first or second RF tubes, the interference is technically known as *cross modulation* or *cross talk.*

If the control grid lead of the first tube is exposed, if the input grid tuned circuit is unshielded, if the set uses a resistance, choke or other *untuned input,* the cross modulation will be quite noticeable with sharp cut-off tubes. In fact, if a local station is involved, its frequency may be almost anywhere in the broadcast band and still cause cross modulation. Interference caused in this way may be produced by two stations having no relation at all between their carriers. When the desired station is tuned out, the interfering station also disappears.

To avoid this undesirable characteristic due entirely to the use of the sharp cut-off type of tube, an effort was made to make a tube whose characteristics were more favorable to minimizing interference. A more desirable tube, for

example, would be one having a more nearly uniform curvature of its characteristic throughout its entire grid range. In this way, the curve being as straight as possible, the tube would produce minimum detection. It would have a *large grid range* with continuously variable slope of the curve resulting in variable gain.

The *mutual conductance* is the most useful characteristic of a tube for determining its amplification in a given circuit. Being the change in plate current divided by a change in grid voltage producing it, you may readily see from the curve of Fig. 9, marked Super- Control, that the slope of the curve becomes less as it progresses from right to left. This means that the plate current or value represented by the vertical direction of the curve, reduces and the grid voltage which is identified by the horizontal direction of the curve increases. The dividend thus decreases fairly evenly as the numerator reduces and the denominator increases. The mutual conductance is the dividend and decreases fairly evenly as the negative bias of the tube is increased.

To construct a tube of the screen grid or pentode type in such a way that it will have these characteristics, the control grid must have a major effect on the control of plate current when the bias is low and minor effect on it when the bias is high. The amplification factor varies with the bias and reduces when bias increases. The term Multi-Mu or Variable-Mu was used extensively for screen grid tubes of this design before RF pentodes became so widely used. These terms have been completely superseded by the terms Super-Control or *remote cut-off*. See your lesson ND-12 for a list of the sharp and remote cut-off types of tubes.

The super control or remote cut-off characteristic is accomplished by making the grid wire mesh taper towards one end or by making it conical. By the latter method, the grid wires nearest the cathode have the greater effect. The standard method of tube design for super control operation is to make the grid wire spacing small at each end and large towards the center. In this way, when cut-off bias is reached as far as each end of the grid is concerned, there is still emission from the central portion of the cathode. The mesh between grid wires is so wide here that the bias must be increased considerably for a complete cut-off of the plate current. This gives the Eg-Ip characteristic an *even, smooth,* remote cut-off type of curvature. The remote cut-off point is marked on the graph of Fig. 9. Note how much farther to the left the cut-off point is with reference to the sharp cut-off point.

Now the grid at any voltage between its minimum bias operating point and cut-off, will amplify in accordance with the slope of the curve at that point. For example, at −3 volts bias for a super-control tube, say of the 6K7 or 12SK7 type, the slope of the curve at this operating point, P1, will be indicated by the dotted line marked SLOPE 1 *tangent* to the curve at point P1. Tangent to the curve means touching it at only one point, not intersecting it. When a ball is placed

on a table, the surface of the table is tangent to the ball.

When the bias is increased to −40 volts, the slope becomes as indicated by the dotted lines marked slope 2 with an operating point P2. Note that this is more horizontal than slope 1. In this case, the plate current changes of grid voltage, and the gain of the tube is considerably reduced. The practical meaning of the latter is that the bias may be increased (the bias is sometimes made variable to permit volume control) without cross modulation taking place. This variable characteristic makes the super-control tube ideal for use with automatic volume control as you will learn later on.

As an example of variable bias control to give a control of volume, assume there are three RF amplifier stages, each with a gain of 100 with −3 volts bias and a gain of 5 per stage with −40 volts bias. In the first case, a 3 *microvolt* signal on the antenna will produce a 3 *volt* signal on the detector as 100×100×100=1,000,000 and 3 microvolts times 1,000,000=3 volts. *Now, if the volume is reduced by adjusting the bias to − 40 volts,* the 3 microvolt signal will produce 5×5×5=125×3=375 microvolts or .375 millivolts at the detector. Under this latter condition, a signal at the first RF grid of .024 volt or 24 millivolts would be required to produce 3 volts at the detector. Thus it is seen that a control of bias in the remote cut-off type of tube will afford a control of volume whereas, if the same type of bias control is used for the sharp cut-off type of tube, cross modulation or interference will take place. This is the reason why so many old model receivers using the sharp cut-off type of tube exhibits this type of interference. Nothing can be done to correct it unless the tube types in the RF stages are changed to the remote cut-off type with rearrangement of the bias control.

In every case where amplifiers are in sucession or in *cascade*—as it is more properly called—if the gain of all stages is reduced by the same factor, the total gain of the entire system is reduced by the cube of that factor. For example, if the gain of each stage is reduced from 100 to 25, a factor of ¼, it will reduce the entire gain to ¼×¼×¼ or 1/64. In the case just explained, the gain is reduced to 1/20 per stage or a total of 1/20× 1/20×1/20 or to 1/8,000 of normal.

Even though a super-control tube is used as a first RF tube, it will not do to allow its grid to swing too far towards the cut-off point or it, too, will detect and allow cross modulation to some extent. For this reason, where high sensitivity of the receiver is not required and the antenna energy is already too large, a means of control is placed in association with the antenna or input circuit of the receiver. In this way, the amount of the grid swing may be kept to a minimum, and the best reception may be obtained.

Two popular methods of sensitivity control are shown in Figs. 10, 11 and 12. Each of these provide a variable *shunt* path for the antenna to ground circuit. Figure 10 shows a potentiometer connected across the antenna input coil. Figure 11 is not to be desired be-

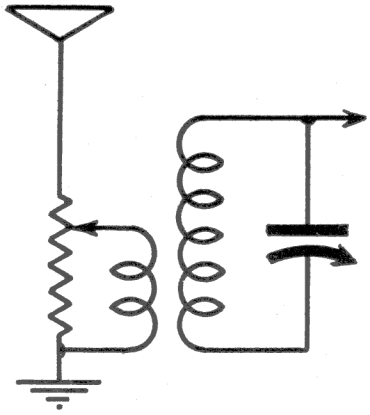


FIG. 10

cause of the length of wire between the control grid and movable contact of the potentiometer. This, if unshielded, will pick up unwanted noise and signals. If it is shielded the capacity of the shield to the grid wire will act as a third shunt path.

It would seem that such methods would serve completely as a volume control but other and more complete methods are needed. By far the most popular is the *bias* method of volume control where control of volume is attained by controlling the input to the RF amplifier—you will learn more about the AF volume control method later on in other lessons.

To return to the RF form of control, if a dual volume control is involved, one section can be used

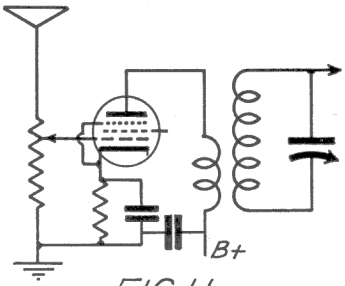


FIG. 11

to vary the bias or to vary the out put of the detector. A portion of a receiver schematic diagram is shown in Fig. 12. Here the amount of signal supplied to the grid of the RF tube is controlled by R_1 while the value of the audio frequency voltage fed to the AF amplifier is controlled by R_2. In this way the volume and sensitivity are controlled at the same time. Notice that R_1 in addition to shunting the antenna coil also adjusts the bias of the two 78 tubes since all cathode current for these tubes must flow through R_1. As the bias is increased, the resistance across the antenna coil is decreased so that the gain of the tubes and the antenna input will be lowered at the same time.

All of the preceding is principally a development to overcome cross modulation; however, other things can happen to the circuit of a super which may cause interference.

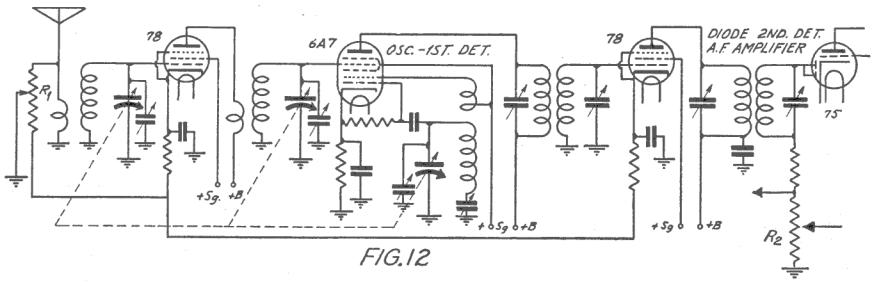


FIG. 12

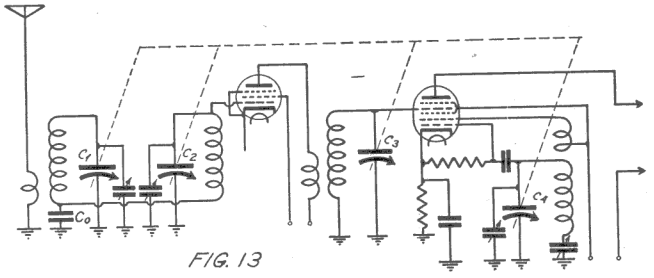


FIG. 13

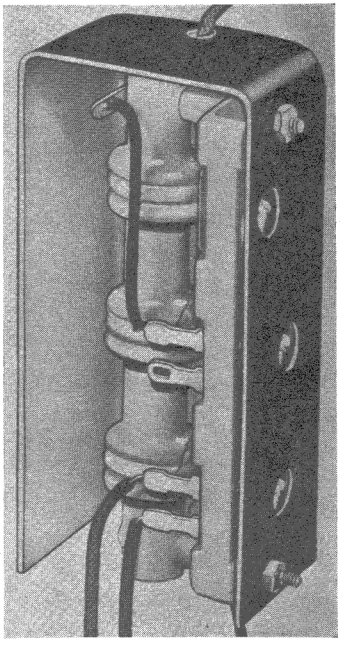
Suppose a super is tuned to 600 KC and that its IF amplifier is tuned to 175 KC. Obviously, the oscillator, in order for a signal to be received, would have to be tuned to 775 or 425 KC to maintain the 175 KC difference from 600 KC. The higher beat frequency is most generally used. Now a strong 950 KC signal may be received even though the receiver is tuned to 600 KC. If this 950 KC signal reaches the first detector, it will form a 175 KC beat ferquency because it differs from the oscillator frequency by exactly 175 KC—that is, 775 −600=175 KC. It makes no difference which is the higher frequency as the IF amplifier will respond to either signal equally. This is a condition where the receiver can and may respond to either a 600 or 950 KC signal. The same principle will, of course, hold true for other frequencies. The prevention of reception of the unwanted signal is entirely a matter of the selectivity of the tuned circuits preceding the first detector. Of course, any extraneous pick-up between the antenna and first detector by wiring, coils, condensers, etc., will also cause this type of interference.

The selectivity of the pretuner may be increased through the use of a band pass filter which is simply a group of tuned stages coupled so that their selectivity effects are combined. One system is shown in Fig. 13 and another in Fig. 14. If these precede the first RF amplifier, the entire set must have a 4 gang condenser tuner as shown by the dotted line in Fig. 13. If, on the other hand, they precede the first detector used as the input tube, which is common design practice for the smaller sets, a three gang condenser is used.

In Fig. 13 the coupling condenser Co is common to both of the first two tuned circuits and the RF drop across it is 1/5 to 1/20 of the total across the tuned circuit, furnishing energy for the second circuit. With this relatively low coupling, the selectivity is quite high. In Fig. 14, the coil LC magnetically feeds L2, the coupling here being small also and the selectivity being high.

Now, if these pre-tuner circuits are tuned to 600 KC, as was suggested previously, a 950 KC signal cannot easily enter to the first detector as these circuits will be 350 KC out of tune.

When you look into a reflecting surface and see a reflection as far back of the surface as the object is in front of it, it is called an *image*. Likewise, when a signal is received as far in KC above the oscillator



Here is another view of a typical IF transformer. It employs 3 tuned circuits for high fidelity reception. Note the three holes in the shield which permit adjusting the three IF trimmer condensers. Courtesy of Meissner.

as the desired signal is below it, it is also called an *image* signal, and when it comes in with a desired signal, it mutually intereferes with it and this type of interference is called *image interference.*

It should be obvious that a 425 KC signal of sufficient intensity to force its way to the first detector grid will also form a 175 KC beat if a signal is also being received at 600 KC without use of the oscillator. This type of interference is usually attended by an audible *heterodyne* or *squeal.* This is called *oscillator image interference* to distinguish it from a signal image interference just described. The remedy for this is to use a wave trap or parallel resonant circuit tuned to the 425 KC or other interfering signal in the antenna circuit, as in Fig. 15. Of course, there are

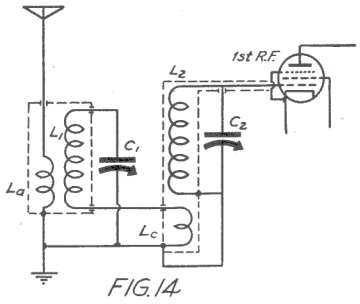


FIG. 14

other possibilities of receiving oscillator image interference, but a wave trap cannot be used for every point in the broadcast band unless it is made to follow the RF tuning as the oscillator follows it. Instead of this the pre-tuner is made sufficiently selective so that this trouble is not likely to occur. Moreover, the Federal Communications Commission allocates the frequency of stations and assigns powers to them so that the probability of this type of interference is minimized. Manufacturers sometimes use a wave trap in the receiver tuned circuit at some point when they know that a certain interfering signal will be encountered.

HARMONIC INTERFERENCE

This type of possible interference is introduced here so that it may be distinguished from other types—not that the receiver de-

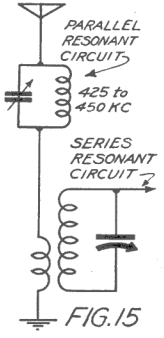


FIG. 15

sign can control it. It is a problem essentially of transmission rather than of reception. If a commercial telegraph transmitter is tuned to 382.5 KC, the second harmonic of it will be 765 KC. If this harmonic wave has sufficient intensity it will be received at what is normally the 765 KC position on the receiver dial and will interfere with signals being received near this frequency such as 760 to 770 KC.

The relative harmonic radiation must be kept below a value determined by the Federal Communications Commission, and in this way there is very little chance of widespread interference of this kind. Some sets, however, located quite near a commercial transmitter, may pick up harmonics, but this cannot be prevented if it is desired to receive other stations at or near that frequency.

The most prevalent type of interference is known as *adjacent channel* interference which derives its name from the fact that the selectivity of the circuit is not sufficient to select one station if there is another just 10 KC away from it. This will be taken up in detail in other lessons of your SAR Course.

THE COMPLETE SUPERHETERODYNE

You have now studied all of the basic superheterodyne circuits except the intermediate frequency amplifier. Before studying the latter, however, a complete superheterodyne circuit will be discussed. This modern complete circuit is shown in Fig. 16. It is schematic diagram of the General Electric Model J-805 receiver. This circuit is presented here as it contains practically all of the super functions which have been covered in your SAR lessons up to this point. Four controls are used with this receiver. One control (S_2) is the *tone* control and *on-off* switch combined. The second control (R12) is the volume control. The third control is, of course, the *manual* tuning condenser $C2_A$ and $C2_B$. The fourth control is a multi-deck switch (S_1) and is used to select the tuning frequency range. This switching system, as used in all wave receivers will be completely treated in a future lesson. One detail of this band switch should be mentioned here, however. When this switch is turned to the "Aut" position it connects the RF and oscillator circuits to a group of five push button tuning elements. These may be adjusted so that when a button is depressed, one of five broadcast stations will be automatically selected. In the case of the RF stage, this is simply accomplished by *substituting* one of the five adjustable trimmer type condensers of the group, C3 (A, B, C, D and E), in place of the variable condenser, $C2_A$. Each of these trimmers must be adjusted to the some capacity as the variable condenser would equal when the latter is tuned to the same frequency as desired for the push button.

In the case of the oscillator, the same result is obtained in a different manner. Instead of tuning one of the oscillator coils with the variable condenser, $C2_B$, one of the permeability tuned units of the group L12 (A, B, C, D and E), is selected. Notice that the induct-

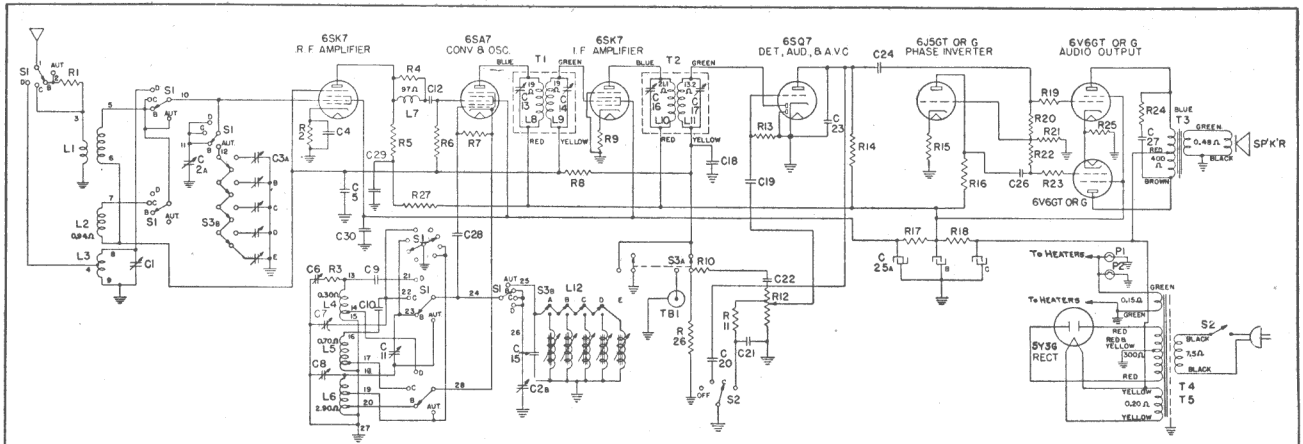


FIG. 16

PARTS DESCRIPTION LIST

Symbol	Description	Symbol	Description	Symbol	Description
C1	"D" band antenna trimmer	C28	47 mmf. mica capacitor	R13	4.7 megohms carbon resistor
C2A	Antenna section of tuning condenser	C29	.01 mfd. paper capacitor	R14	470,000 ohms carbon resistor
C2B	Oscillator section of tuning condenser	C30	.01 mfd. paper capacitor	R15	3300 ohms carbon resistor
C3	Antenna station selector trimmer strip	L1	"B" and "C" band Beam-a-Scope	R16	68,000 ohms carbon resistor
C4	.01 mfd. paper capacitor	L2	"C" band antenna coil	R17	8200 ohms 2 W carbon resistor
C5	0.1 mfd. paper capacitor	L3	"D" band Beam-a-Scope	R18	1800 ohms 3 W carbon resistor
C6	"D" band oscillator trimmer	L4	"D" band oscillator coil	R19	1000 ohms carbon resistor
C7	"C" band oscillator trimmer	L5	"C" band oscillator coil	R20	150,000 ohms carbon resistor
C8	"B" band oscillator trimmer	L6	"B" band oscillator coil	R21	56,000 ohms carbon resistor
C9	.008 mfd. paper capacitor	L7	R.F. interstage coil	R22	270,000 ohms carbon resistor
C10	2400 mmf. ±5% mica capacitor	L12	Oscillator station selector coil strip	R23	1000 ohms carbon resistor
C11	"B" band padding trimmer	P1	Dial lamp, MAZDA No. 44	R24	5600 ohms carbon resistor
C12	100 mmf. mica capacitor	P2	Dial lamp, MAZDA No. 44	R25	180 ohms 1 W carbon resistor
C15	750 mmf. ±5% silvered mica	R1	1000 ohms carbon resistor	R26	470,000 ohms carbon resistor
C18	220 mmf. mica capacitor	R2	47 ohms carbon resistor	R27	1000 ohms carbon resistor
C19	.02 mfd. paper capacitor	R3	27 ohms carbon resistor	S1	Band switch
C20	.003 mfd. paper capacitor	R4	10,000 ohms carbon resistor	S2	Tone control switch
C21	.005 mfd. paper capacitor	R5	3300 ohms carbon resistor	S3A	Phono-FM-Tel switch
C22	.005 mfd. paper capacitor	R6	47,000 ohms carbon resistor	S3B	Station selector switch
C23	220 mmf. mica capacitor	R7	22,000 ohms carbon resistor	T1	1st I.F. transformer
C24	.03 mfd. paper capacitor	R8	2.2 megohms carbon resistor	T2	2nd I.F. transformer
C25A	10 mfd. 300 V. dry electrolytic	R9	150 ohms carbon resistor	T3	Output transformer
C25B	15 mfd. 300 V. dry electrolytic	R10	47,000 ohms carbon resistor	T4	50-60 cycle-power transformer
C25C	30 mfd. 350 V. dry electrolytic	R11	82,000 ohms carbon resistor	T5	25 cycle power transformer
C26	.03 mfd. paper capacitor	R12	2 megohms volume control (0.5-meg-ohm tap)		
C27	.002 mfd. paper capacitor				

ance selected is tuned by the fixed condenser, C_{15}. Instead of varying the capacity of an LC circuit, in this case the capacity is fixed and the inductance is varied by moving the iron dust core.

The push buttons are arranged so that $C3_A$ and $L12_A$ or $C3_B$ and $L12_B$, etc., will be selected at the same time by the same button. The tuning range selector is shown in Fig. 16 in the manual tuning position for the broadcast range.

This receiver is provided with an inside antenna or *loop* which is built into the cabinet. Provision is made so that an outside antenna and ground may be connected. This is necessary in certain isolated localities where the signal strength is low. The energy received by either type of antenna is fed to the grid of the RF stage. This is a triple grid super control remote cut-off type known as a 6SK7. The normal bias for this tube is supplied by the cathode resistor, R_2, with its by-pass condenser, C_4. The variable bias or AVC will be briefly described later in this lesson. The gain for this stage is stated by the manufacturer as 6.5 at 1000 KC.

The amplified RF is supplied to the first detector (or converter and oscillator) by *resistance capacity* coupling. The reason for the choice of this method of coupling is to simplify the switching necessary for multiband reception. By using this coupling method, no group of coils and their associated switches are necessary at this point as the RC coupling will respond to all frequencies to which the receiver may be tuned. The RF present at the top end of R_5 is transferred through R_4 and L_7 (which are in parallel) to C_{12} and thence to the control grid of the 6SA7. Thus, the received signal is made to appear in the plate circuit of the 6SA7. The oscillator frequency is introduced into the 6SA7 by way of grid No. 1 (pin No. 5) and the cathode of the same tube. This is a relatively simple oscillator circuit, and you may easily trace the circuit. Notice that the cathode is connected to the tap of L_6 and then to ground. Notice also the oscillator *trimmer* (C_8) across L_6 and also the padder (C_{11}) in *series* with the oscillator blocking condenser (C_{28}). The small *voltage* necessary to operate the oscillator *grid* (No. 1) as an anode is supplied by the electrons driven to it from the cathode. The number of these electrons accumulated, and, consequently, the potential, is regulated by the resistor R_7. The net result is that this oscillator frequency is made to appear in the plate circuit of the 6SA7. The two frequencies are combined (RF and Osc. frequencies) and the difference frequency of 455 KC is selected by the IF transformer, T_1, and is supplied to the 6SK7 IF tube. The output of this IF stage is supplied to one plate of the duodiode-triode 6SQ7 detector through IF transformer T_2. The normal bias for the 6SK7 IF amplifier is supplied by R_9.

Notice that the IF is fed to the 6SQ7 cathode from T_2 through the condenser C_{18}; thus this IF is placed on the diode plate and cathode of this tube. One diode plate of the 6SQ7 is grounded and not used. The DC resulting from the rectification of this IF by the diode

will appear across R_{26} which is the load resistor for the diode.

This DC is supplied to the *grids* of the first three tubes through resistor R_8 as a variable AVC voltage, the value of which will depend on the value of the IF voltage rectified. You may overlook the AVC here as a forthcoming lesson is devoted exclusively to this interesting improvement.

The varying DC or audio frequency across R_{26} is supplied to R_{12} through R_{10} and the coupling condenser C_{22}. Resistor R_{10} is a protective series resistor, and its function is to limit currents entering the volume control circuit when switch $S3_A$ is in the position to allow phono input (record reproduction) from an outside source through jack TB_1. Notice here that when $S3_A$ is in the phono position, the output of T_2 is grounded thus preventing signals from interfering with the phono output. A tone control is provided by switch S_2. The volume control is a tone compensating type which will be fully described in another lesson. The movable contact of the volume control, R_{12}, supplies the AF to the grid of the triode section of the 6SQ7. Any RF remaining in the plate circuit of the 6SQ7 is returned to ground by condenser C_{23}. The AF now amplified by the triode section of the 6SQ7 is resistance capacity coupled to the grid of one 6V6 output tube. The AF voltage is also supplied to a *voltage divider* comprising R_{20} and R_{21}. As R_{20} is 150,000 ohms and R_{21} is 56,000 ohms, approximately ¼th of the voltage supplied to this voltage divider is supplied to the grid of the 6J5 phase *inverter*. The output of this phase inverter is supplied to the second 6V6 output tube. As there is no input transformer for the push-pull output tubes, and as the AF potentials supplied to the two grids must be of opposite instantaneous potential (out of phase) some means must be used to bring about this condition. Because the input and output voltages of a tube are opposite in phase, it is a simple matter to supply the two output tubes from the input and output circuits of the 6J5 tube. One other unusual fact concerning this circuit is the use of an RC filter for the plate supply. In this case, R_{17} is an 8,200 ohm, 2 watt resistor, and R_{18} is an 1,800 ohm, 3 watt resistor. Resistors R_{17} and R_{18} are here acting as filters in the place of the usual inductance. Condenser $C25_A$ is 10 mfd., 300 V, $C25_B$ is 15 mfd., 300 volt and $C25_C$ is a 30 mfd. 350 V condenser.

PERMEABILITY TUNING

In recent years the trend of tuning has been to employ variable inductance core tuning instead of trimmer or padder condensers. Many modern receivers will use variable RF preselector air trimmers with variable inductance tuning for the oscillator and IF stages. Others will use variable inductances altogether. This application finds its greatest usefulness in *push button* tuning systems, which you will study in detail in a later lesson. In reality, the amount of actual wire wound inductance is not changed in the variable inductance tuning systems. For this reason the variable inductance reference is not quite correct. Instead the position of

the core of the coil is varied which brings about a varying permeability of the core which, in turn, has the effect of varying the inductance. As has been stated, iron or alloy dust cores are used for the tuning coils. The core dust is mixed with a suitable but non-magnetic cement binder. This mixture is then compressed into suitable forms. By proper mixture of the binder and core dust a very effective core can be formed which will have a minimum of eddy current loss. The core is often moulded around a small threaded screw made from brass. This screw may be made to travel over a given path in relation to a nut in a fixed position. By turning the screw head, the moulded core may be made to enter or leave the inside of the coil form and, thus, in effect, vary its inductance. Too, another possible arrangement is to leave the core in a fixed or stationary position and vary the coil in relation to the core. It is more practical, however, to vary the core in relation to the coil on account of the wire leads connecting to it.

The magnetic dust particles are made in different sizes. The size of these particles and the total amount of them in proportion to the binder controls the amount of permeability and the Q of the coil —something you will learn more about in the next lesson. The smaller the magnetic dust particles the less will be the permeability of the core and the higher the frequency to which the coil may effectively tune.

The dust cores used most frequently are made from iron, permalloy and molybdenum permalloy. The latter has the lowest losses and, therefore, gives the highest gain. Pure iron dust has the greatest loss and, therefore, has less gain characteristics. Such coils are engineered to give a very minimum of loss and in high gain circuits their loss is not noticed. One of the greatest reasons for employing iron or iron alloy cores in tuned circuits is because *a very efficient high gain coil can be constructed in a small space*—an ideal condition in modern all wave circuits where many parts must be crowded into limited space.

The circuit of Fig. 16 shows one way in which permeability tuning may be indicated. In this case, arrows are included through the coil symbol of L_{12} to indicate permeability tuning. In other diagrams, the same thing might be indicated by including a core symbol with arrows just above the coil symbol. In adjusting the individual coils of L_{12} in Fig. 16 each one is set to tune the coil at one frequency. Once the adjustment is made the oscillator circuit will remain tuned to that particular frequency, and when its corresponding push-button is pressed, it automatically tunes the circuit to the desired frequency. Such permeability tuned coils as those in Fig. 16 will hold their adjustment a long time. Like all adjustable tuning elements, they do, however, in time get completely out of adjustment. For this reason, hot sealing wax is placed on the adjustable screw threads where they make contact with the nut. When the wax cools it becomes hard and will prevent vibrations from gradually destroying the fine tuning adjustment. You will

learn more about practical tuning adjustments and permeability tuning in your Master Service Course lessons.

REDESIGN OF OLD TYPE RECEIVERS

When screen grid tubes were first put on the market, it was a great advance in RF amplification. The first of these tubes were the 22 and 32 types for battery operation and the 24 and 24A for AC operation. These were quickly followed by the 36, 57, 77, etc. Several manufacturers made many models using these tubes and today thousands of them are still in use. Most of these sets show a strong degree of cross modulation interference. Three general methods of volume control are employed in them: (1) the screen grid voltage is varied, (2) the control grid bias is varied and (3) some form of antenna input control is used. This refers, of course, to the use of the tubes as RF amplifiers. None of these controls eliminated the undesirable cross modulation feature as mentioned earlier in this lesson. In fact, variable control grid and screen grid voltage controls only made a bad situation worse because these brought about more detector action in the RF amplifier circuits. Where the screen grid voltage was fixed, the control grid voltage was varied. The tubes having a sharp cut-off plate current characteristic were, naturally, pushed beyond their limit and unwanted detection occurred in the RF stages. This situation can be corrected in many of the older type receivers *if the circuits are redesigned.* It rarely pays in the long run, however, because sometimes the changes required are extensive. Possible replacement tubes types are the 6K7, 78, 6AB7, 6SK7, 7A7, 7B7, 7H7, 6SS7, 6D6, 6E7, 6U7, 6S7, 12SK7, 12K7, 14A7, 12B7, etc. Most of the older receivers using the undesirable type screen grid tube were of the TRF type which means a variable bias control must be worked out for them in order to take advantage of the *super control* feature. Thus the RF tubes should have a mimimum bias resistor in their cathode circuits and then, in addition, a variable resistor should be inserted in series with the minimum bias resistor so that as more resistance is included a greater bias is placed on the control grids of the tubes. In many circuits it is desirable to feed a bleeder current from some portion of the B+ circuit into the circuit of the variable bias resistance so that a sufficient voltage drop will occur across it to bias the control grids *an increasing amount.* This is necessary because as the control grid bias is increased the plate current is reduced and soon it becomes impossible to obtain enough plate current to increase the grid bias a sufficient amount. Thus, if a bleeder current is taken from the B+ circuit the control grid bias can be made almost independent of the plate current of the controlled tubes. In AVC controlled circuits, this variable bias control is automatically adjusted according to the strength of the signal. You will learn all about this automatic action in a later lesson.

When *super control* tubes are used to replace the older screen grid type, the first consideration

is to replace the old type sockets with sockets which will fit the new type tubes. Then proper filament voltage should be provided. The screen grid voltage divider circuit will have to be worked out for the new tubes. Also, a new plate voltage divider circuit may be needed. The older receivers used tubes with an approximate plate voltage of 180 volts whereas the newer type tubes should have about 250 volts on their plates. This may call for a new power transformer and perhaps a new filter circuit. All in all, many engineering changes might have to be made to obtain the best features of the *super control* tubes. For this reason and because of the expense and time required to redesign a circuit it does not, in general, pay to redesign an old receiver to obtain features of new tubes and circuits.

Your next lesson will take up other RF and IF tuning principles. The lesson following this one will treat automatic volume control, and the one following it will take up the complete super type receiver using a six-color circuit which will help to correlate all of your previous studies on the super type of receiver.

These questions are designed to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. A circuit tunes to 3000 KC with a capacity value of 180 mmfd. What value must the total circuit capacity be to tune to 9000 KC?

No. 2. What are the two methods of making the oscillator tuning condenser track with the RF over a band of frequencies?

No. 3. State the difference between the high frequency trimmer and the low frequency padder with respect to their position in the circuit.

No. 4. If a receiver is tuned to 1460 KC, at what frequency must the oscillator be adjusted for an IF of 460 KC?

No. 5. What is the purpose of the super control tubes?

No. 6. In what two ways does R1 in Fig. 12 control the volume of the signal?

No. 7. For what purpose is the wave trap in Fig. 15 used?

No. 8. In what way can signal image interference be minimized?

No. 9. In what way would the reproduction be affected if a 77 tube was used in the 1st RF stage of Fig. 12.

No. 10. How many resonant circuits are employed for the signal in the circuit of Fig. 13?